Appendix to the June 27, 2012 Draft Vision for Clean Air: A Framework for Air Quality and Climate Planning

ARB Vision Model Documentation

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ARB Vision Model Documentation

The VISION model was originally developed by Argonne National Laboratory to provide estimates of the potential energy use, oil use and Carbon emission impacts of advanced light and heavy-duty vehicle technologies and alternative fuels through the year 2050. ARB staff modified the 2011 VISION model to estimate upstream and downstream (i.e. tailpipe) emissions associated with the operation of light duty vehicles and heavy duty trucks.

The following documentation outlines the data sources and methods used to estimate criteria and greenhouse gas emissions from the mobile sectors considered for the Vision project. There are three corresponding models: a heavy duty truck model; a light duty vehicle model; and an off-road model for locomotives, ocean going vessels (OGV), aviation, in-use off-road, cargo handling equipment and harbor craft. The heavy duty truck and light duty models are based on the Vision model. Tailpipe emissions analyses for off-road sectors were based on ARB's official emissions inventories with upstream emissions calculated within the heavy duty truck Vision model.

Please refer to the Argonne documentation at http://www.transportation.anl.gov/modeling_simulation/VISION/ to understand how the base Vision model functions. ARB's models for California are available at http://www.arb.ca.gov/planning/vision/vision.htm.

Heavy Duty Vehicles (HDV)

Background

The modified Vision model allowed staff to input various new vehicle sales fractions, fuel economy improvements, fleet mix changes, activity growth, and new vehicle standards. The heavy duty scenario inputs are described in detail in the heavy duty truck sector section.

ARB staff made various modifications to the VISION model in order to make it California-specific and to include additional vehicle categories such as in-state and out-of-state trucks. The fleet characteristics modified in Vision to account for California operation include fuel economy, population, accrual rates, sales rates, survival rates, growth rates and tailpipe emission rates. These modifications are described in more detail below.

Heavy duty fleet assumptions were obtained from ARB's official on-road motor vehicle emission inventory model (EMFAC2011). Estimating emissions from on-road vehicles is explained in more detail in the EMFAC2011 documentation (http://www.arb.ca.gov/msei/modeling.htm).

The categories modeled in the modified Vision model include:

- Heavy heavy-duty diesel trucks (HHDT)
- Medium heavy-duty diesel and gasoline trucks (MHDT)
- HHDT and MHDT natural gas trucks
- HHDT diesel-hybrid trucks
- MHDT diesel-hybrid and gasoline-hybrid trucks
- HHDT and MHDT plug-in diesel hybrid trucks
- HHDT and MHDT electric trucks
- HHDT and MHDT hydrogen trucks

Model Inputs

1. **Base 2010 Vehicle Population**

   The 2010 base vehicle population was taken directly from the EMFAC2011 HDV model.

2. **New Truck Sales**

   Staff used the population of age zero (i.e. new) trucks from EMFAC2011 for each calendar year (2011-2035) for three geographic domains: South Coast Air Basin, San Joaquin Valley Air Basin, and statewide. This data was used as sales inputs for the VISION model and was grouped into the following four categories:

   a. Heavy Heavy-duty Instate Trucks: This category includes all diesel-fueled heavy-duty trucks (gross vehicle weight rating (GVWR) > 33,000 lbs) that operate within the California state boundary.
   b. Heavy Heavy-duty Out of State (OOS) Trucks: This category includes all diesel-fueled heavy-duty grucks (GVWR > 33,000 lbs) that operate both inside and outside the California state boundary.
   c. Medium Heavy-duty Diesel Trucks: This category includes all diesel-fueled medium and light heavy-duty trucks (10,000 < GVWR < 33,000) that operate within the California state boundary.
   d. Medium Heavy-duty Gasoline Trucks: This category includes all gasoline-fueled medium and light heavy-duty trucks (10,000 < GVWR < 33,000) that operate within the California state boundary.

   EMFAC2011 only provides truck sales through 2035. Beyond 2035 and up to 2050, sales were projected based on a linear trend of new sales between 2017 and 2035. For each of the four categories, the total number of sales in each calendar year was split among the different fuel/technology options depending on the scenario market penetration rate for each fuel/technology type (i.e. sales percentage).

3. Survival Rates

For diesel and gasoline conventional vehicles that are subject to the Statewide Truck and Bus Rule, staff developed calendar year and model year specific survival rates to take into account the impacts of the rule and migration of vehicles from out of state. Survival rates were derived from EMFAC2011 by calculating the population change from one given calendar year to another for each model year over time.

For new truck technologies confined to California (in-state), staff assumed that these vehicles would follow similar survival rates as their conventional counterparts. For example, MHD gas HEVs follow the same survival rate as conventional gasoline MHDTs with some exceptions. Survival rates for out-of-state new technology trucks were based on the average survival rate from EMFAC2011 for calendar years 2000 through 2005 but staff removed the impact of migration on the survival rates since these technologies may be less prevalent in other parts of the country.

Survival rates were applied to population starting in 2011 and were specific to each vehicle category.

4. Accrual Rates

The accrual rates (miles/year/vehicle) were derived from EMFAC2011. The rates vary as a function of age and represent statewide average values for each of the four vehicle categories. Combining these accrual rates with vehicle populations provided vehicle miles travelled (VMT) estimates for each vehicle category and geographic domain.

5. Vehicle Miles Travelled (VMT)

VMT in EMFAC2011 was derived using the methodology developed for the 2010 amendments to the ARB Statewide Truck and Bus Rule (http://www.arb.ca.gov/regact/2010/truckbus10/truckbusappg.pdf). Specifically, VMT was grown assuming an average growth rate based on data from the California Energy Commission and the U.S. Energy Information Administration. The methodology also applied adjustments to account for the current economic recession using data from the California Department of Finance and U.S. Bureau of Economic Analysis.

The initial VMT in the current VISION model was calculated by combining statewide average accrual rates and vehicle populations. Staff then used EMFAC2011 VMT values to develop correction factors in the VISION model to account for any over- or underestimations of VMT values as a result of using average accrual rates. These correction factors were derived using the following formula:

Correction factor = Initial VMT / EMFAC2011 VMT

By applying the correction factors, initial VMT estimates were adjusted upward or downward to match the total VMT values provided in the EMFAC2011 model. For calendar years beyond 2035 and up to 2050, staff projected EMFAC2011 VMT values based on a linear trend of total VMT between 2017 and 2035. These projected values were also used to develop the VMT correction factors described previously for years 2035 through 2050.

6. Fuel Efficiency

Fuel efficiency (miles per gallon) was specific to fuel type and vehicle category as described below.

a. Diesel and Gasoline Fueled Trucks: Fuel efficiencies for diesel-fueled and gasoline trucks were specific to age and calendar year. These fuel efficiencies were statewide average values and were calculated in the following manner using EMFAC2011 output:

Fuel Efficiency (mpg) = VMT (miles) / Fuel Consumption (gallons)

b. Alternative Fuel/Technology Trucks: Fuel efficiencies for alternative fuel/technology trucks were equal to the fuel efficiencies of conventional diesel vehicles but were multiplied by a correction ratio to acquire miles per gallon equivalent values. Fuel efficiencies for technologies considered in scenarios are described in the documentation for the truck sector.

7. Emission Factors

The NOX, PM and ROG emission factors (grams/mile) were specific to fuel type and vehicle category as described below.

a. Diesel and Gasoline Fueled Trucks: Emission factors for diesel-fueled and gasoline trucks were specific to age and calendar year. These emission factors were statewide average values and were calculated in the following manner using EMFAC2011 output:

EF (g/mile) = Emissions (grams per day) / VMT (miles)

b. Alternative Fuel/Technology Trucks: Emission factors for electric, hydrogen and the electric component of plug-in hybrid trucks were equal to zero (i.e. no tailpipe emissions). For natural gas and diesel hybrids, staff assumed the emission factors were equal to the lifetime average emission factors from 2010 model year diesel-fueled trucks and did not vary as a function of calendar year or age. For gasoline hybrids, emission factors were equal to the lifetime average emission factors from 2010 model year gasoline-fueled trucks.

Scenarios

Depending on the scenario, staff adjusted the VISION model inputs to accommodate any changes in future technology sales, fuel efficiencies, emission standard changes, and VMT reductions.

a. New Technology Sales: When modified, total new sales of trucks were split among the different alternative fuel/technology types. These sales ratios were calendar year specific.
b. Fuel Economy Improvements: The fuel efficiencies for conventional diesel and gasoline trucks were specific to model year and age. For alternative fuel/technology trucks, the fuel efficiencies were specific only to model year and adjusted according to the fuel efficiency ratios previously described.
c. New Emission Standards: The emission factors were modified by assuming the implementation of new tailpipe NOx emission standards. In addition, any fuel efficiency increases were applied as emission reduction factors for alternative fuel/technology trucks.
d. Operational Efficiencies: VMT reductions were applied to all trucks. This change impacted fuel consumption and criteria pollutant emissions.

Light-Duty Vehicles (LDV)

The light duty fleet characteristics assumptions were obtained from ARB's official on-road motor vehicle emission inventory model (called EMission FACtor model, or EMFAC2011, available at http://www.arb.ca.gov/msei/modeling.htm) and ARB's official database for the Advanced Clean Car regulation (http://www.arb.ca.gov/regact/2012/leviiighg2012/levappt.pdf).

Staff modified the VISION model to include estimates for the following vehicle technology types:

- Gasoline Vehicles
- Ethanol Vehicles
- Diesel Vehicles
- Natural gas Vehicles
- Gasoline Hybrid Vehicles
- Gasoline/E85 Flexible Fuel Hybrid Vehicles
- Diesel Hybrid Vehicles
- Gasoline Plug-In Hybrid Vehicles
- Diesel Plug-in Hybrid Vehicles
- Electric Vehicles
- Fuel Cell (Hydrogen) Vehicles

The fleet characteristics modified in VISION to account for California specific operation included the base year fuel economy, population, accrual rates, sales rates, survival rate, growth, and tailpipe emission rates. These modifications are described in more detail below.

Model Inputs

1. **2010 Base year Vehicle Population**

   Population data for calendar year 2010 were obtained from EMFAC2011 by age, and were distributed into 22 age categories (0-20, and 20+). EMFAC2011-LDV estimated vehicle populations using registration data from the Department of Motor Vehicles data from the 2009 registration year to update the populations in each vehicle class for 45 age groups and 69 geographic areas. It was assumed that all vehicles in 2010 were operating on either conventional gasoline or conventional diesel technologies.

2. **New Vehicle Sales**

   Total new vehicle sales for Autos and Light Trucks were obtained separately from the EMFAC2011 database for calendar years 2010-2035, and were projected out to 2050 by using the ACC population growth assumptions from 2035-2050.

3. Technology forecasts

Technology fractions for new vehicle sales were consistent with ARB's mandate for Pavley I and Advanced Clean Cars regulations. Additional modifications were made to the technology fractions to account for changes in fuel efficiency and emission standards as described later in the Scenario section.

4. Population

In order to calculate the population in calendar years beyond 2010:

a. New vehicle populations (Age 0) were calculated using new vehicle sales and corresponding technology fractions for the calendar year

b. Older vehicle populations (Ages > 0) were calculated as the surviving population of the selected model year vehicle from the previous calendar year (the previous year's populations for Age (n-1) were multiplied with survival rates for Age n vehicles)

5. Fuel Economy

The fuel efficiencies (miles per gallon) were specific to fuel type and vehicle category. Fuel economy data were detailed for each technology at a decade interval. Fuel economies for the intervening years were calculated by interpolating the fuel economy numbers for the two closest decades

6. Accrual Rates

The accrual rates (miles/year/vehicle) were derived from EMFAC2011 output for Autos and Light Trucks separately. The rates vary as a function of age and represent statewide average values for each of the vehicle categories. Combining these accrual rates with vehicle populations provided initial vehicle miles travelled (VMT) estimates for each vehicle category and geographic domain. This approach helped in creating vehicle use data consistent with the EMFAC inventory wherein newer vehicles accrue more annual mileage than older vehicles.

7. Survival Rates

Survival rates were derived from EMFAC2011 data by calculating the population change by model year in two consecutive calendar years (2009 and 2010). For example, in order to calculate the survival of Age 0 vehicles, staff divided the population of 2009 Model year vehicle in 2010 by their population in 2009. Survival rates were calculated for both gasoline and diesel varieties of Autos and Light Trucks separately, and applied to their corresponding technologies.

8. Vehicle Miles Traveled (VMT)

EMFAC2011-LDV used the latest VMT and speed profile data provided by regional transportation planning agencies (RTPA) from the Southern California Association of Governments (SCAG), Bay Area Metropolitan Transportation Commission (MTC), San Diego Association of Governments (SANDAG), and San Joaquin Valley Councils of Government. In the absence of recent RTPA data, the model used default speed distributions and estimated VMT as a function of vehicle population (from DMV) and mileage accrual rates (from the Bureau of Automotive Repair SmogCheck program).

The VMT values (miles/year) in the model were calculated by combining the vehicle populations with the accrual rates in the following manner:

$$\mathrm{VMT}_{\text{Technology}} = \sum \mathrm{Population}_{\mathrm{MYr}} \times \mathrm{Accrual}_{\mathrm{Age}} \left(\frac{\text{miles}}{\text{vehicle . year}} \right)$$

Staff then used EMFAC2011 Default VMT values to develop correction factors in the VISION model to account for any over or underestimations of VMT values as a result of using average accrual rates. These correction factors were derived using the following formula:

$$\text{Correction factor} = \frac{\sum \mathrm{VMT}_{\text{Technology}}}{\text{Default EMFAC2011 VMT}}$$

By applying the correction factors, initial VMT estimates were adjusted upward or downward to match the total VMT values provided in the EMFAC2011 model. In order to forecast VMT from 2035 to 2050, ARB analyzed the statewide population growth factors embedded in EMFAC2011-LDV module. Staff then applied the annual population growth rate in the last available year (2034-2035) to subsequent years to forecast the 2035 population for every year out to 2050. The resulting population forecast was coupled with the default survival rates and annual VMT accrual data used in EMFAC2011-LDV to calculate the total VMT.

In general, regional transportation planning agencies did not reflect the impact of the economic cycle on VMT, and instead dampened future VMT forecasts in light of the slower economic recovery from the recent economic recession. As a result the recession is generally handled through long term rather than short-term forecasts in EMFAC2011-LDV.

9. Criteria Pollutant Emission Factors

The NOx, PM and ROG emission factors (grams/mile) were specific to fuel type and vehicle category as described below.

a. Gasoline and Diesel: Emission factors were extracted for each age group for all calendar years from 2010-2025 for the three regions separately from EMFAC2011. The emission factors for all calendar years beyond 2025 were assumed to be the same as the 2025 emission rates by age.

$$\text{EF (g/mile)} = \frac{\text{Total Emissions} \left(\frac{\text{tons}}{\text{year}}\right) * 2000 \left(\frac{\text{lbs}}{\text{ton}}\right) * 453.59 \left(\frac{\text{g}}{\text{lb}}\right)}{\text{VMT} \left(\frac{\text{miles}}{\text{year}}\right)}$$

This method accounts for model year specificity including the impacts of deterioration. Additional modifications were made to the emission factors to account for changes in fuel efficiency and emission standards as described later.

b. All other technologies: Since the emission rates for newer technologies were not available in EMFAC2011, they were inferred from the emission rates for gasoline and diesel vehicles by factoring their fuel economy improvements. For example, a technology with twice the fuel economy of a gasoline vehicle was assumed to have half as much emissions per unit mile.

In order to account for deterioration of vehicles, lifetime emission rates for gasoline and diesel vehicles were used for calculating the new technology emission rate. Average lifetime emission factors for each calendar year from 2010-2025 for the three regions were obtained from EMFAC2011. The emission factors for all calendar years beyond 2025 were assumed to be the same as the 2025 emission rates. Tail pipe emission rates for hydrogen and electric vehicles were input as zero for all criteria and greenhouse gas (GHG) pollutants.

$$\text{Lifetime Emission Factor}_{\text{New Technology}} = \text{Lifetime EF}_{(\text{GAS/ DSL})} \times \frac{\text{Fuel Economy}_{(\text{GAS/ DSL})}}{\text{Fuel Economy}_{\text{New Technology}}}$$

10. Weighted Emission Factor

Resulting unit emission factors for the technology fleet were calculated by weighting the Emission Factors by their corresponding VMT to account for the fact that newer vehicles (with lower emission rates) are driven more than older vehicles (which have higher emission rates due to deterioration)

$$\text{Weighted Emission Factor } \left(\frac{\text{g}}{\text{mile}}\right) = \frac{\sum \text{Population}_{\text{MY}} \times \text{Accrual}_{\text{Age}} \times \text{Emission Factor}_{\text{MY}}}{\sum \text{Population}_{\text{MY}} \times \text{Accrual}_{\text{Age}}}$$

11. Criteria Pollutant Emission Calculations

Emissions were calculated by multiplying the total VMT and the weighted unit emission rates

$$\text{Total Emissions } \left(\frac{\text{tons}}{\text{day}}\right) = \frac{\text{Total VMT } \left(\frac{\text{miles}}{\text{year}}\right) \times \text{Weighted Emission Factor } \left(\frac{\text{g}}{\text{mile}}\right)}{454 \left(\frac{\text{g}}{\text{lb}}\right) \times 2000 \left(\frac{\text{lb}}{\text{ton}}\right) \times 365 \left(\frac{\text{days}}{\text{year}}\right)}$$

Scenarios

Depending on the scenario, staff adjusted the VISION model inputs to accommodate any changes in future technology sales, fuel efficiencies, emission standard changes, and VMT reductions.

a. New Technology Sales: When modified, total new sales of vehicles were split among the different alternative fuel/technology types. These sales ratios were calendar year specific.

b. Fuel Economy Improvements: The fuel efficiencies for conventional diesel and gasoline vehicles were specific to model year and age. For alternative fuel/technology vehicles, the fuel efficiencies were specific only to model year and adjusted according to the fuel efficiency ratios previously described.

c. New Emission Standard: The emission factors were modified by assuming the implementation of new tailpipe NOx and PM emission standards. These modifications were applied as Emission Factor Correction Factors, and were applied to account for reductions from the Advanced Clean Cars Regulation that weren't reflected in EMFAC2011. This was done by running a baseline scenario with only conventional fuel vehicles and modifying the emission factor correction factors until the appropriate reductions were achieved. The reductions were developed to effectively match the benefits from the Advanced Clean Cars regulation.

d. VMT Reductions: When modified VMT reductions were applied to all vehicles. Activity Correction Factors were applied to account for expected reduction in annual VMT in future calendar years. This change impacted fuel consumption and criteria pollutant emissions.

Off-road Categories

Background

The 2011 Vision Model originally developed by the Argonne National Laboratory and then modified for use by ARB in the context of passenger vehicles and heavy-duty trucks was not used for the off-road categories. Modifying the Vision model to accommodate these categories would have been very time and resource intensive. For this reason staff utilized the existing inventory models that have been developed in support of the regulations for the various off-road categories.

Methodology and Data Sources

To estimate the emissions associated with each of the strategies in the off-road scenarios, staff used existing inventories developed for the State Implementation Plan (SIP) and regulations as a starting point. These inventories are listed in Table 1. The time horizon for each inventory is provided in this table as well.

Table 1. Data Sources for Offroad Emission Inventory Categories

Offroad Category	Time Horizon	Source
Aircraft (Criteria Pollutants)	2005-2020[1]	SIP Inventory
Aircraft (GHGs)	2000-2009[2]	2009 GHG Inventory
Cargo Handling Equipment	2000-2030[3]	2011 Rule Amendment
Commercial Harbor Craft	2008-2025[3]	2010 Amendment
Locomotive	2000-2035	1992 Locomotive Inventory
Ocean-Going Vessel (24 nm)	1975-2030[3]	2011 Amendment
Ocean-Going Vessel (100 nm)	1975-2030[3]	2011 Amendment
Offroad (Construction)	2009-2029[3]	2010 Rule Amendment

[1] Data can be accessed at http://www.arb.ca.gov/app/emsinv/fcemssumcat2009.php
[2] Data can be accessed for 2000-2009 at
http://www.arb.ca.gov/cc/inventory/doc/doc_index.php
Projected data for 2020 can be accessed at
http://www.arb.ca.gov/cc/inventory/data/forecast.htm
[3] Data can be accessed at
http://www.arb.ca.gov/msei/categories.htm#offroad_motor_vehicles

Estimating the emissions inventory for scenario options are described in detail below for a sample category. The steps involve utilizing ARB's existing emissions inventories, projecting those emissions to 2050 and then applying the reductions specific to the scenario option (e.g. new technologies, operational efficiencies, and fuels).

The construction sector is used as an example to illustrate the methodology used to estimate emissions for these categories. The specific inputs for the other categories are discussed at the end of this example.

Step 1: *Download the data for the following categories (in the case of construction equipment, from http://www.arb.ca.gov/ports/cargo/amd2011docs/cheimodel.mdb)*

- Engine size
- Load factor
- Activity
- Fuel consumption
- NOx emissions
- PM emissions
- ROG emissions
- CO_2 emissions

The results from the statewide inventory are shown for specific years in Table 2. Note that the inventory specifically provides engine size, load factor, and activity. CO_2 emissions are not given explicitly, but the fuel output in pounds can be multiplied by the estimated carbon content of the fuel (10,138 g CO2/gallon of fuel) to estimate carbon emissions.

Table 2. Construction-related inventory data for specific years

Offroad (construction)	2009	2010	2020	2030
Horsepower-hours	9,402,489,478	8,461,417,667	12,868,824,755	15,703,669,252
Fuel (pounds)	1,349,400,019	1,214,342,039	1,846,997,687	2,254,504,554
Fuel (gallons)	190,056,341	171,034,090	260,140,519	317,535,853
NOx (tons/year)	24,974	22,356	18,389	9,470
PM (tons/year)	1,227	1,106	839	337
CO2 (mt/year)	1,926,791	1,733,944	2,637,305	3,219,178
ROG (tons/year)	2,103	1,907	1,761	1,212

Step 2: *Estimate emission rates for baseline conditions for the time horizon in the existing ARB inventories.*

Emission rates in grams per gallon were calculated by dividing emissions by gallons of fuel consumed. ARB staff estimated the average emission factors for each calendar year, which is shown in Table 3 for the statewide inventory.

Table 3. Estimated construction-related efficiencies for specific years

Offroad (construction)	2009	2010	2020	2030
Fuel Rate (hp-hrs/gallons)	49	49	49	49
NOx (g/gallon)	119	119	64	27
PM2.5 (g/gallon)	5.9	5.9	2.9	1.0
CO_2 (g/gallon)	10,138	10,138	10,138	10,138
ROG (g/gallon)	10.0	10.1	6.1	3.5

Step 3: *Estimate emission rates for baseline conditions through 2050.*

As Table 3 shows, within the current inventory the fuel efficiency remains constant and emission rates trend downward for criteria pollutants with time as a result of the impacts of the regulation and natural turnover. ARB staff then projected each of these emission rates through 2050 for this exercise. Under the business as usual scenario, the emission rates would continue to decrease until they reached the lowest emission rate possible (a rate for the Offroad category equivalent to a 100% Tier 4 fleet).

For the Offroad category in the statewide inventory, ARB staff assumed that the trends shown between 2024 and 2030 – the last few years of the current rule's inventory) would continue beyond 2030, with the only constraint being that the fleetwide emission factor would not fall below the Tier 4 emission factor (the fleetwide factor that would represent a 100% Tier 4 fleet). These constraints are approximately 16.4 g/gallon for NOx and 0.25 g/gallon for PM2.5. The constraint, beyond which no further reductions could be made without technologies beyond those already in place, is projected as being reached in 2037 for NOx and in 2044 for PM2.5. Figure 1 shows the projections for NOx in the construction category. Table 4 shows the results for all pollutants and a number of future calendar years.

Figure 1. The statewide NOx emission rate for construction equipment, as modeled within earlier inventories from 2009 to 2030 and then projected to 2050

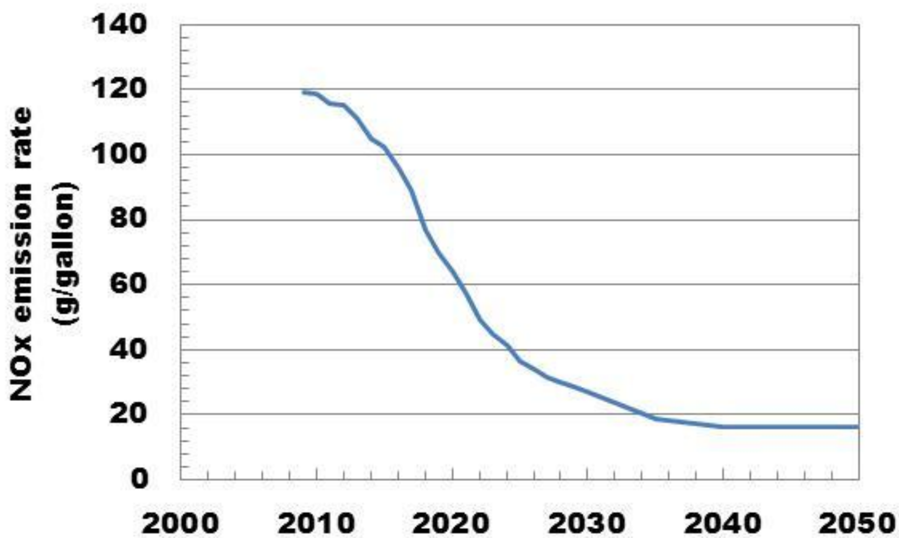

Table 4. Projected fuel consumption and emission rates for construction equipment (projection based on inventory between 2024 and 2030).

Offroad (construction)	2024	2030	2040	2050
BSFC (hp-hrs/gallons)	49	49	49	49
NOx (g/gallon)	42	27	16	16
PM2.5 (g/gallon)	1.7	1.0	0.4	0.3
CO_2 (g/gallon)	10,138	10,138	10,138	10,138
ROG (g/gallon)	4.4	3.5	2.3	1.6

Step 4: *Estimate future activity and resulting emissions*

Given the projected emission factors, the last step for the baseline scenario involved projecting growth in activity through 2050. Statewide off-road construction equipment activity, measured in effective horsepower-hours, was then be multiplied by the emission factors shown in Table 4 to estimate business as usual emissions. These results are shown in Table 5.

Table 5. Projected construction-related inventory data

Offroad (construction)	2024	2030	2040	2050
Horsepower-hours	14,657,310,730	15,703,669,252	17,621,468,885	19,764,425,424
Fuel (pounds)	2,103,605,313	2,254,504,554	2,530,264,597	2,838,972,911
Fuel (gallons)	296,282,438	317,535,853	356,375,295	399,855,340
NOx (tons/year)	13,568	9,470	6,430	7,215
PM (tons/year)	564	337	140	111
CO2 (mt/year)	3,003,711	3,219,178	3,982,597	4,468,500
ROG (tons/year)	1,452	1,212	912	697

The next steps in this process involve accounting for emissions impacts of the various scenarios considered. Some of the scenario changes considered included:

- Increased efficiency
- Operational efficiency improvements
- Use of diesel/electric battery hybrid
- Use of fuel cell vehicles
- Use of plug-in electric and/or
- NOx reductions specifically associated with the development of Tier 5

To calculate the emission impacts associated with each of these strategies, ARB staff estimated the amount of energy (in btus) associated with the level of activity in the baseline scenario. This estimate of energy is necessary to estimate upstream emissions for fuel production. For the construction category, the 8,461,417,667 horsepower-hrs estimated for calendar year 2010 is equal to 0.022 quadrillion BTUs.

The total energy required under each of the scenarios would be that required under the baseline scenario, minus any reductions achieved via efficiency increases or activity reductions. For the construction category, for example, activity was reduced by 2 percent in 2020 and by 10 percent in 2050 for Scenario 3, with activity reductions interpolated for intervening years.

The remaining energy consumption was allocated to the various technology types (i.e. conventional, fuel cells, hybrids, etc.) according to the fleet makeup defined by the scenario. For some technologies like hybrids there were additional energy savings because of energy efficiencies.

After allocating the energy consumption among the various technology types, staff estimated tailpipe emission reductions associated for each category. Fuel cell and electric vehicles were assumed to have no tailpipe emissions. Other technologies were assumed to have reductions from conventional vehicles based on reductions identified in the Scenarios.

Upstream emissions were calculated based on the energy consumption estimates described above using emission rates that are described in more detail in the energy sector discussion. Upstream calculations were done for all the off-road categories in the modified Vision model described in the heavy duty truck modeling section.

In addition to the various technologies described above the scenarios also included a NOx reduction from a new emissions standard. The specific Tier 5 reductions are sector-specific and described in the sector scenario discussions.

Other Off-Road Sector Category-Specific Methodologies

The previous section described the emissions methodology for the construction equipment sectors. The following sections describe the process for the other offroad inventory categories.

Aircraft

Data regarding aircraft activity were provided by the local governments for both greenhouse gases and criteria pollutants. The activity data were also categorized into different fuel sources, jet fuel and aviation gasoline. The most recent available GHG inventory (calendar year 2009) and the current 2020 projections were used to estimate a growth rate for fuel in the years between 2009 and 2020, with the same growth rate projected forward to 2050. The fuel was directly converted to GHGs, with the fuel in the scenarios other than the baseline affected by the increased efficiencies reflected by the scenarios.

Because criteria pollutants are currently estimated with data provided by local districts, and the data reflect only emission levels rather than activity or emission rates per unit of modeled activity, future emission levels were estimated simply by projecting beyond 2020 at the growth rate forecast for emissions between 2015 and 2020. The scenarios that incorporate increases in fuel efficiency from the baseline are assumed to incorporate reductions in criteria pollutants that parallel the increases in fuel efficiency.

For both cases, the increase in fuel efficiency is applied only to those aircraft using jet fuel and not those using aviation gasoline. (Jet fuel represented 90 percent of all aircraft activity in 2010).

Cargo handling equipment (CHE)

For CHE, as with construction equipment, the activity and the emission rates within the current inventory were projected beyond the last year of the current inventory (2030) to the last year of this inventory (2050). For Scenario 3, the growth rate was adjusted to 3 percent from the current inventory's growth rate if it exceeded 3 percent. Emission factors were capped at the current Tier 4 rates, 0.19 g/hp-hr for NOx and 0.0044 g/hp-hr for PM2.5, unless Tier 5 was introduced. The energy requirements, which are estimated from the diesel fuel requirements under the current inventory and the baseline scenario, are allocated between diesel and alternative energy sources in Scenarios 2 and 3.

Commercial Harbor Craft (CHC)
The activity and emission rates for CHC were projected beyond the last year of the current inventory (2025) to the last year of this inventory (2050). The activity growth modeled in the current inventory is negligible, so this factor was not adjusted in any scenario. Emission factors were capped at Tier 4 levels, 2.49 g/hp-hr for NOx and 0.056 g/hp-hr for PM2.5, unless Tier 5 was introduced. The energy requirements, which are estimated from the diesel fuel requirements under the current inventory and the baseline scenario, are allocated between diesel and alternative energy sources in Scenarios 2 and 3.

Locomotives
Locomotive activity was divided into four categories using ARB's historical inventory model: line-haul, switcher, metrolink, and passenger. The model projects aggregate fuel consumption and emission levels until 2035. Staff used these numbers to estimate emission rates and project those, along with fuel consumption, for each category forward to 2050. The baseline representation of Tier 4 locomotives was inferred from the growth rate for activity and the anticipated initial deployment of Tier 4 locomotives in 2015. The scenarios modeled accounted for an increase in the representation of Tier 4 locomotives or the introduction of Tier 5 locomotives, with the impact upon emissions being estimated by the difference in the emission rates for the two categories and the representation of each tier within the overall fleet (activity). The scenarios also account for different energy sources – electric and/or diesel hybrid – which are introduced at varying levels in Scenarios 2 and 3 but not in Scenario 1.

Emission factors were capped at 1.00 g/hp-hr for NOx and 0.0138 g/hp-hr for PM2.5., unless Tier 5 locomotives were introduced. U.S. EPA fuel consumption estimates were used for line haul and other activity (20.8 hp-hr/gallon for line-haul locomotive activity and 15.2 hp-hr/gallon for all other activity).

Ocean-going vessels (OGV)
OGV activity and emission factors were projected forward from the last year of the current inventory (2030) to the last year of this inventory (2050) using a methodology similar to that described for other categories. Activity was also divided into the categories of hotelling and non-hotelling (anchorage, maneuvering, and transit). The scenarios modeled included increased shore

power for hotelling and increased IMO Tier 3 representation among vessels for older vessels, as well as cleaner diesel and increased efficiency. The levels for each varied between the specific scenarios. The NOx emission rate was not allowed to go below 1.96 kg/MW-hr, the current IMO Tier 3 standard. Also, growth rates were capped at 3% beyond 2030 for Scenario 3, which is less than the growth rate currently modeled for South Coast and statewide activity between 2020 and 2030.

Domains for inventories

For OGV, harbor craft and aviation domain also played a role. Specifically, analyses for ocean-going vessels were completed for both 24 nautical miles and 100 nautical miles based on the domains used for GHG and SIP assessments. Similarly, the greenhouse gases associated with aircraft activity represent only the activity for intrastate flights but for the entire length of each flight. The criteria pollutants associated with aircraft activity represent all flights that originate or land in California but only the portion that occurs below 3000 feet.

Lastly, the energy consumption for these sectors was input to the Vision heavy duty truck model to estimate the corresponding upstream emissions and to look at the results for all the sectors combined.

Fuel and Electricity Production

The VISION model developed by Argonne National Laboratory includes upstream fuel and electricity emission factors for greenhouse gases and total fuel consumption estimates. ARB staff retained the structure of the original VISION model, but modified emission factors and feedstock choices to characterize California scenarios.

The following fuels from the original VISION model were used in the California scenarios. The list below only captures fuel types, details of feedstocks, including renewable sources, are described in the next section.

- Gasoline
- Diesel
- Natural gas
- Ethanol
- Hydrogen
- Electricity
- Jet fuel

Model Inputs

1. **Fuel and electricity feedstocks and emission factors**

   Similar to the downstream vehicle emissions, staff modified the VISION model to include criteria emissions for upstream fuel production and delivery. The VISION model already includes greenhouse gas emission inputs. For each feedstock listed below, the following emission factors are captured as inputs to the modified model. Using total energy consumption from the downstream vehicle model, in units of BTU, total emissions can be calculated.

   - Carbon equivalent greenhouse gas emissions, MMTC/Quad BTU (million metric tons of Carbon per quadrillion units of fuel)
   - NOx, g/mmBTU (grams per million BTU)
   - VOC, g/mmBTU
   - PM 2.5, g/mmBTU
   - SOx, g/mmBTU

   The following table shows specific fuel feedstocks used in the modified VISION model and California scenarios. The table also shows the three different sources of emissions data used to identify inputs.

Fuel type	Feedstock	Data source
Gasoline	Petroleum	CA GREET (ARB) [1]
	Renewable, forest wood	2011 GREET (ANL) [2]
Diesel	Petroleum	CA GREET (ARB)
	Biodiesel, soybeans	CA GREET (ARB)
	Renewable, forest wood	UC DAVIS [3]
	Renewable, MSW [a]	UC DAVIS
Ethanol	Corn	CA GREET (ARB)
	Corn stover	CA GREET (ARB)
	Switchgrass	CA GREET (ARB)
	Forest wood	UC DAVIS
	Sugarcane	CA GREET (ARB)
Hydrogen	Natural gas	CA GREET (ARB)
	Renewable electricity	CA GREET (ARB)
	Biomass	CA GREET (ARB)
	Coal with CCS [b]	CA GREET (ARB)
	Direct solar thermal conversion	CA GREET (ARB)
CNG	Natural gas (fossil)	CA GREET (ARB)
Jet fuel	Petroleum	CA GREET (ARB)
	Renewable, forest wood	2011 GREET (ANL)
Electricity	Coal	CA GREET (ARB)
	Coal with CCS	CA GREET (ARB)
	Natural gas	CA GREET (ARB)
	Nuclear	CA GREET (ARB)
	Renewable electricity [c]	CA GREET (ARB)

a) MSW = municipal solid waste
b) CCS = Carbon capture and storage
c) Includes large hydroelectricity

According to recent research from the California Energy Commission and UC Davis[4], the most plentiful biomass feedstocks in the western states are

[1] Air Resources Board, Low Carbon Fuel Standard, CA-GREET lifecycle analysis computational modeling tool, http://www.arb.ca.gov/fuels/lcfs/lcfs.htm
[2] Argonne National Laboratory, GREET Model, 2011 version used for ARB Vision project, http://greet.es.anl.gov/main
[3] Parker, Nathan C, "Modeling Future Biofuel Supply Chains using Spatially Explicit Infrastructure Optimization," doctorate dissertation, UC Davis, 2011.

forest wood thinnings, and municipal solid waste (residential or industrial landfill diversions).

Scenarios

In developing scenarios, the model has the functionality to vary several parameters in the energy sector. These functionalities are described below.

1. **Fuel blending and electricity production mix**

   Many of the fuels used directly in vehicles are a combination of several fuel feedstocks listed in the previous table. An example would be E85 which is comprised of 85 percent ethanol and 15 percent gasoline by volume. The model can blend a large number of the feedstocks, and can simulate varying blend levels over time. For example, in the scenarios created by staff, the diesel fuel used by vehicles included an increasing blend of renewable diesel displacing conventional petroleum diesel over time.

   This functionality can be used to simulate varying feedstock types for an individual fuel type as well. For example, a varying mix of feedstocks was simulated for hydrogen, including renewable sources and natural gas. This same approach was used for electricity where the production sources of electricity varied over time, where staff assumed an increasing share of renewables and in one case, Carbon capture and storage (CCS) with fossil fuels.

2. **Emission factor geographic boundary assumption**

   For all fuel sources, an assumption was made about how far upstream the analysis considered in determining emission factors. For greenhouse gas emissions, staff assumed a “global” reach where the emission factor included all emissions upstream of the vehicle regardless of where the emissions occurred. As a result, fuel production and delivery stage emissions are included even if they occur outside of California. Additionally, natural Carbon sequestration from the growth of biomass is also included.

   For criteria emissions, however, a more limited boundary assumption was used given the local impact concern. Once the full global upstream emission factor is added to the model, a multiplier is included to simulate a geographic boundary. For all alternative fuels, staff assumed a 50 percent multiplier which represents the fraction of upstream criteria emissions that occur in the state or in the air basin depending on the simulation modeled.

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[4] University of California at Davis, “Strategic Assessment of Bioenergy Development in the West,” Final Report, Western Governor’s Association, September 1, 2008.

A value of 50 percent was chosen for simplicity given the large uncertainties in determining the location of emissions.

3. Fuel consumption choice in flex fuel vehicles (FFVs)

In addition to varying the fuel composition by feedstock types, flex-fuel vehicles have a unique ability to fuel with varying blend levels of gasoline and ethanol. The fuel used in FFVs can vary between conventional gasoline and E85. For the California scenarios, staff assumed most FFVs consume conventional gasoline today, but increasingly consume E85 by 2020. Beyond 2020, the FFVs on the market begin to consume gasoline which has a renewable gasoline blend, displacing ethanol in the market.

4. Biomass resource restriction

Energy resources have supply limitations, dependent on either physical supply restrictions (e.g. oil reserves) or production limitations. For the California scenarios created, staff only assumed one specific supply limitation, that of biomass physical limits on crop growth. Based on research by UC Davis, a biomass limit of 6 billion gallons gasoline equivalent (BGGE) was used for the California market. This limit of biomass applies to the full transportation sector, not just passenger vehicles.